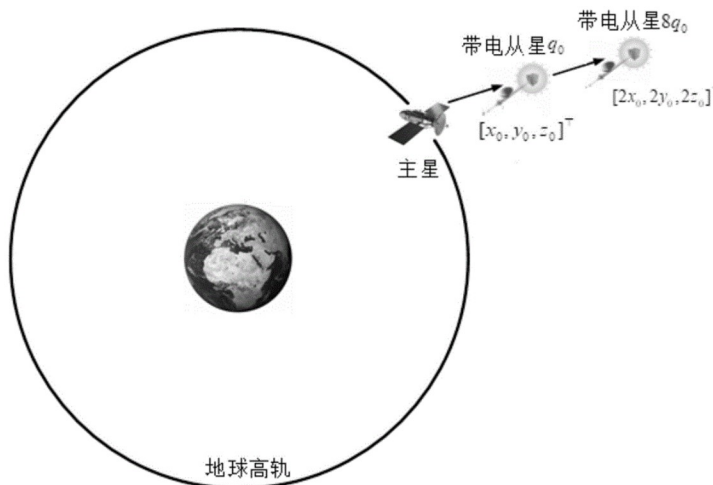


Lorentz force suspension method based on artificial magnetic field

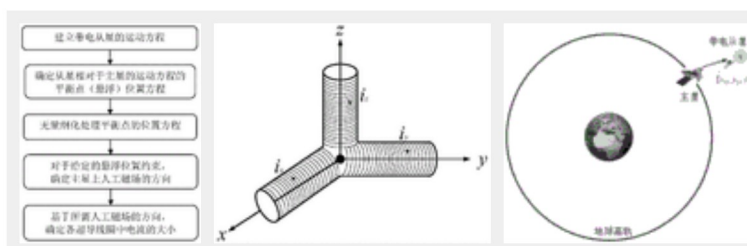
Abstract

translated from Chinese

The invention relates to the field of aerospace, in particular to a Lorentz force levitation method based on an artificial magnetic field, which is suitable for levitation observation tasks using charged spacecraft on high earth orbits. The invention uses the analytical expression between the position coordinates of the equilibrium point of the motion equation and the direction of the artificial magnetic field, and introduces a suitable dimension to dimensionless the position equation of the equilibrium point, and then obtains the direction of the artificial magnetic field corresponding to any floating position, and gives The magnitude of the current required in the superconducting coil in the direction of the desired artificial magnetic field is determined. The present invention only needs to adjust the magnitude of the current in the three orthogonal superconducting coils on the main star to obtain any direction of the artificial magnetic field, and to achieve the required suspension task at the equilibrium point. The electric charge of the can further adjust the suspension position without consuming additional chemical fuel, and has application prospects in the space observation mission of close suspension.



Images (3)



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Classifications

■ [H02N15/04](#) Repulsion by the Meissner effect

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Claims (2)

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1. A Lorentz force suspension method based on an artificial magnetic field is characterized in that: the method comprises the following steps:

firstly, establishing a motion equation of an electrified slave star under the action of an artificial magnetic field with an adjustable direction above a master star;

the main star runs on the earth high orbit, the electrified auxiliary star cannot be disturbed by the earth magnetic field, the artificial magnetic field on the main star generates Lorentz force to the auxiliary star, and the artificial magnetic field on the main star spins and has adjustable direction; lorentz force is used for realizing suspension of the charged slave star relative to the master star; the equation of motion of the charged slave star in the local horizontal local vertical coordinate system with the origin at the master star is expressed as,

$$\begin{cases} \ddot{x} - 2n\dot{y} - 3n^2x = f_x \\ \ddot{y} + 2n\dot{x} = f_y \\ \ddot{z} + n^2z = f_z \end{cases} \quad (1)$$

in which the position vector of the charged slave star

$$\mathbf{r} = (x, y, z)^T ;$$

Velocity vector of charged slave satellite

$$\dot{\mathbf{r}} = (\dot{x}, \dot{y}, \dot{z})^T ;$$

n is the average angular velocity of the orbit of the main satellite;

$$\mathbf{f}_L = (f_x, f_y, f_z)^T$$

to charge the lorentz force experienced by the satellite,

$$\mathbf{f}_L = \frac{q}{m} \mathbf{v}_r \times \mathbf{B} = \frac{q}{m} \cdot (\dot{\mathbf{r}} - \boldsymbol{\omega}_c \times \mathbf{r}) \times \mathbf{B} \quad (2)$$

wherein,

q

m

charge to mass ratio of charged slave star, v_r For the velocity of the charged slave star relative to the master star,
 ω_c The angular velocity of the artificial magnetic field on the main satellite; b is the strength of the artificial magnetic field, and is defined as:

$$\mathbf{B} = \frac{B_0}{r^2} \nabla \times (\mathbf{N} \times \mathbf{r}) \quad (3)$$

in the formula,

$$\mathbf{N} = [N_x, N_y, N_z]^T$$

is the direction of the artificial magnetic field, and the angular velocity can be expressed as

$$\boldsymbol{\omega}_c = \omega_c [N_x, N_y, N_z]^\top,$$

ω_c is the magnitude of the angular velocity; b is the magnetic flux of the magnetic flux,

$$r = \sqrt{x^2 + y^2 + z^2}$$

is the distance of the slave star relative to the master star;

the three components of the Lorentz force in equation (2) are developed and obtained,

$$\left\{ \begin{array}{l} f_x = \frac{q}{m} \frac{B_0}{r^3} \left[\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} (\dot{y}z - \dot{z}y) - \omega_c (xN_z - zN_x) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} z - N_z \right) \right. \\ \quad \left. + \dot{z}N_y - \dot{y}N_z + \omega_c (yN_x - xN_y) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} y - N_y \right) \right] \\ f_y = \frac{q}{m} \frac{B_0}{r^3} \left[\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} (\dot{z}x - \dot{x}z) - \omega_c (yN_x - xN_y) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} x - N_x \right) \right. \\ \quad \left. + \dot{x}N_z - \dot{z}N_x + \omega_c (zN_y - yN_z) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} z - N_z \right) \right] \\ f_z = \frac{q}{m} \frac{B_0}{r^3} \left[\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} (\dot{x}y - \dot{y}x) - \omega_c (zN_y - yN_z) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} y - N_y \right) \right. \\ \quad \left. + \dot{y}N_x - \dot{x}N_y + \omega_c (xN_z - zN_x) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} x - N_x \right) \right] \end{array} \right. \quad (4)$$

further expanding the Lorentz force component in equation (4), we can obtain

$$\begin{aligned}
f_x &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{y} \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] + N_y \dot{z}(x^2 + z^2 - 2y^2) \right. \\
&\quad - 3y\dot{z}(xN_x + zN_z) - \omega_c(xN_y - yN_x) \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] \\
&\quad \left. - \omega_c(xN_z - zN_x) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right\} \\
f_y &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{x} \left[-3z(xN_x + yN_y) + N_z(x^2 + y^2 - 2z^2) \right] - N_x \dot{z}(y^2 + z^2 - 2x^2) \right. \\
&\quad + 3x\dot{z}(yN_y + zN_z) + \omega_c(yN_x - xN_y) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\
&\quad \left. + \omega_c(yN_z - zN_y) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right\} \\
f_z &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{x} \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] + N_x \dot{y}(y^2 + z^2 - 2x^2) \right. \\
&\quad - 3x\dot{y}(yN_y + zN_z) - \omega_c(zN_x - xN_z) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\
&\quad \left. - \omega_c(zN_y - yN_z) \left[3y(xN_z + zN_x) - N_y(x^2 + z^2 - 2y^2) \right] \right\}
\end{aligned} \tag{5}$$

Determining a balance point position equation of a relative motion equation of the slave star under the action of the direction-adjustable artificial magnetic field above the master star;

the suspension position is the point at which the slave star is stationary relative to the master star, i.e. the equilibrium point of equation (1) of relative motion, such that

$$\dot{x} = \dot{y} = \dot{z} = 0, \ddot{x} = \ddot{y} = \ddot{z} = 0,$$

The equation for the position of the equilibrium point is obtained as follows,

$$\left\{ \begin{aligned}
&3n^2x + \frac{q}{m} \frac{B_0\omega_c}{r^5} \left\{ (zN_x - xN_z) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right. \\
&\quad \left. + (yN_x - xN_y) \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] \right\} \\
&\quad (yN_x - xN_y) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\
&\quad \left. + (zN_y - yN_z) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right\} = 0 \\
&n^2z + \frac{q}{m} \frac{B_0\omega_c}{r^5} \left\{ (zN_y - yN_z) \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] \right. \\
&\quad \left. + (xN_z - zN_x) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \right\} = 0
\end{aligned} \right. \tag{6}$$

at the equilibrium point of the motion equation, the earth attraction borne by the charged slave star is offset with the Lorentz force from the artificial magnetic field, so that the slave star is static relative to the master star, namely the relative position between the master star and the slave star is unchanged, and the relative speed and the relative

acceleration are zero;

step three, carrying out dimensionless treatment on the formula (6) in the step two;

introduction of unit length

$$a^{\star} = \left| \frac{B_0}{n} \frac{q}{m} \frac{1}{\beta} \right|^{1/3},$$

$\beta = n/\omega_c$ The equation (6) is subjected to non-dimensionalization processing for the ratio of the angular velocity, and the position coordinate without dimension is recorded as

$$[X, Y, Z]^{\top} = [x, y, z]^{\top} / a^{\star},$$

The equilibrium point position equation for obtaining the dimensionless equation of motion is:

$$\begin{cases} 3X + \frac{1}{R^5} \left\{ (ZN_X - XN_Z) [3Z(XN_X + YN_Y) - N_Z(X^2 + Y^2 - 2Z^2)] \right. \\ \quad \left. + (YN_X - XN_Y) [3Y(XN_X + ZN_Z) - N_Y(X^2 + Z^2 - 2Y^2)] \right\} \\ \quad (YN_X - XN_Y) [3X(YN_Y + ZN_Z) - N_X(Y^2 + Z^2 - 2X^2)] \\ \quad - (ZN_Y - YN_Z) [3Z(XN_X + YN_Y) - N_Z(X^2 + Y^2 - 2Z^2)] \\ \quad \left. Z + \frac{1}{R^5} \left\{ (ZN_Y - YN_Z) [3Y(XN_X + ZN_Z) - N_Y(X^2 + Z^2 - 2Y^2)] \right. \right. \\ \quad \left. \left. + (XN_Z - ZN_X) [3X(YN_Y + ZN_Z) - N_X(Y^2 + Z^2 - 2X^2)] \right\} \right\} = 0 \end{cases} \quad (7)$$

wherein,

$$R = \sqrt{X^2 + Y^2 + Z^2}$$

the dimensionless distance between the charged slave star and the master star,

$$[N_X, N_Y, N_Z]^T = [N_x, N_y, N_z]^T$$

is a unit directional component of the artificial magnetic field, the capital subscripts are intended to be dimensionless coordinates

$$[X, Y, Z]^T$$

Keeping the uniformity;

step four, constraint according to the given dimensionless suspension position

$$[X_0, Y_0, Z_0]^T,$$

Determining the direction of an artificial magnetic field on the main satellite;

dimensionless coordinates of the levitation position in the actual task are

$$[X_0, Y_0, Z_0]^T,$$

I.e. the position coordinates of the balance point are

$$[X_0, Y_0, Z_0]^T,$$

Substituting equation (7) and solving, the unit direction component of the artificial magnetic field can be obtained as follows:

$$\begin{cases} N_x = \sigma \sqrt{\frac{X_0^2 [5Y_0^2 Z_0^2 + 8Z_0^4 - X_0^2 (27Y_0^2 + 40Z_0^2)]^2}{4R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \\ N_y = \sigma \zeta \frac{-Y_0 [-18X_0^4 + Z_0^2 (Y_0^2 - 2Z_0^2) + X_0^2 (9Y_0^2 + 28Z_0^2)]}{2\sqrt{R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \\ N_z = \sigma \zeta \frac{-3Z_0 [-8X_0^4 + Y_0^2 Z_0^2 + X_0^2 (Y_0^2 + 8Z_0^2)]}{2\sqrt{R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \end{cases} \quad (8)$$

in the formula,

$$R_0 = \sqrt{X_0^2 + Y_0^2 + Z_0^2} ;$$

zeta is formula

$$X_0 [5Y_0^2 Z_0^2 + 8Z_0^4 - X_0^2 (27Y_0^2 + 40Z_0^2)]$$

Symbolic function, defined as

$$\zeta = \begin{cases} 1, & \text{if } X_0 [5Y_0^2 Z_0^2 + 8Z_0^4 - X_0^2 (27Y_0^2 + 40Z_0^2)] \geq 0 \\ -1, & \text{if } X_0 [5Y_0^2 Z_0^2 + 8Z_0^4 - X_0^2 (27Y_0^2 + 40Z_0^2)] < 0 \end{cases} \quad (9)$$

Alternatively, σ can have a value of 1 or -1, which indicates that for any given levitation position $[X_0, Y_0, Z_0]^T$ There are two possible artificial magnetic field directions, two sets of solutions; and the two directions are opposite; it should be noted that, in order to ensure N_x, N_y And N_z Are all real, dimensionless, coordinate divisions The amount must be such

that: when X is present₀When the signal is not equal to 0, the signal is transmitted,

$$Z_0^2 - 3X_0^2 > 0,$$

that is to say

$$|Z_0| > \sqrt{3} |X_0|;$$

When X is present₀When 0, there is no constraint condition;

step five, determining any actual relative position based on the direction component of the artificial magnetic field solved in the step four

$$[x_0, y_0, z_0]^T$$

The magnitude of the current required for levitation;

because the artificial magnetic field on the main satellite is formed by three orthogonal high-temperature superconducting coils, the artificial magnetic fields with different directions can be obtained by adjusting the current in the superconducting coils; the relationship between the magnetic flux and the parameters of the superconducting coil is as follows

$$B_0 = \frac{\mu_0}{4\pi} n_c i_c \pi r_c^2 \quad (10)$$

Wherein, $\mu_0 = 4\pi \times 10^{-7} \text{N/A}^2$ is a vacuum permeability, n_c is the number of turns of the coil, i_c is the intensity of the current, r_c is the radius of the coil;

the number of turns and the radius of the three superconducting coils are the same, and magnetic fields in different directions are realized by adjusting the current in the coils; note the book

$$i_c^*$$

For the nominal current, combining the formula (8) to obtain the currents in the three coils respectively

$$\begin{cases} i_x = i_c^* N_x \\ i_y = i_c^* N_y \\ i_z = i_c^* N_z \end{cases} \tag{11}$$

In the formula i_x , i_y and i_z corresponding to currents in the superconducting coils along the x-axis, y-axis and z-axis, respectively

the combination of equations (8) and (11) gives a specific magnetic flux B_0 For a given number of turns and radius of the superconducting coil, a dimensionless relative position is achieved

$$[X_0, Y_0, Z_0]^T$$

The magnitude of the current required for levitation;
for a given actual levitation position coordinate

$$[x_0, y_0, z_0]^T,$$

It needs to be dimensionless to obtain the corresponding dimensionless coordinates

$$[X_0, Y_0, Z_0]^T,$$

The magnitude of the current required in the three coils can be obtained by utilizing the step four; the specific method comprises the following steps: firstly, according to a nominal current i_c And a coil parameter $n_c r_c$ The magnetic flux B is calculated by the formula (10)_{0(ii)} a Next, based on the given charge-to-mass ratio

$$\frac{q}{m}$$

$$m$$

And the angular velocity ratio β , calculating the unit length

$$a^{\star} = \left| \frac{B_0}{n} \frac{q}{m} \frac{1}{\beta} \right|^{1/3}$$

And thus the actual levitation position coordinates

$$[x_0, y_0, z_0]^T$$

Converting into dimensionless position coordinates

$$[X_0, Y_0, Z_0]^T;$$

Finally, the formula (8) is used to solve N_x, N_y, N_z is substituted into the formula (11) to obtain the required current

$$[i_x, i_y, i_z]^T,$$

Thereby realizing arbitrary realityPosition of

$$[x_0, y_0, z_0]^T$$

Suspension of (2).

2. The method of claim 1, wherein: the change of the suspension position can be realized through the electrification amount of the slave star, and the specific method comprises the following steps:

since step five is based on the given

q

m

Descripti

translated from Chinese

A Lorentz

agnetic field

technical 1

The invention relates to the field of aerospace, in particular to a Lorentz force levitation method based on an artificial magnetic field, which is suitable for levitation observation tasks using charged spacecraft on high earth orbits. The unit length is determined, therefore, when the values of the parameters n and β are kept unchanged, the levitation at different positions can be realized by changing the charged quantity q of the charged slave star, and the relationship between the actual quantity of electricity and the new levitation position is as follows

Background technique

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propulsion, the Lorentz force only needs to charge the slave star and deploy an artificial magnetic field that can

adjust the direction on the host star and can achieve specific tasks without consuming fuel, because the

Lorentz force is suspended in the future space. It has great application prospects in tasks such as close-up

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of the suspension design has not been proposed.

$$q = q_0 \left(\frac{ds}{ds_0} \right)^3 \quad (12)$$

wherein q is the charged quantity of the slave star, and s is the levitation coordinate of the slave star.

$$[x_0, y_0, z_0]^T$$

(corresponding to a levitation distance of s_0)

Prior art [2] (Y.Cheng,G.Gómez,J.J.Masdemont,J.Yuan.Analysis of the Relative Dynamics of a Charged Spacecraft Moving under the Influence of aMagnetic Field.Communications in Nonlinear Science and Numerical Simulation,62:307- 338, 2018.) gives the equilibrium points when the directions of the artificial magnetic field are radial, tangential and normal, respectively. However, in the prior art [2], only the magnetic field directions

along the three basic coordinate axes are considered, and the position where the suspension can be achieved is only a specific equilibrium point, and the suspension observation at other positions that may be required in practical tasks cannot be realized.

To sum up, the technology of using Lorentz force under artificial magnetic field to achieve levitation is still in the initial stage of research, and it is impossible to achieve levitation at any position.

SUMMARY OF THE INVENTION

The purpose of the present invention is to provide a Lorentz force levitation method based on an artificial magnetic field in order to solve the problem that the prior art cannot realize any point suspension observation. This method realizes the levitating motion of the charged slave star relative to the master star at any position based on the Lorentz force, that is, it remains stationary relative to the master star. The artificial magnetic field on the main star is composed of three orthogonal superconducting coils. The direction of the artificial magnetic field can be adjusted by adjusting the magnitude of the current in the superconducting coils, so as to obtain a balance point at any coordinates, so as to achieve suspension at any position; The suspension position can also be further adjusted by changing the charge amount on the slave star. Both of the above scenarios do not require the consumption of fuel to maintain a suspended state. The invention has the advantages of no chemical propellant pollution, and has good potential applications in space observation missions equipped with photosensitive payloads (such as cameras).

The purpose of the present invention is achieved through the following technical solutions.

A Lorentz force levitation method based on artificial magnetic field, by establishing the motion equation of the charged slave star under the artificial magnetic field with adjustable direction on the main star, making the relative velocity and acceleration zero, and obtaining the equilibrium point of the motion equation (that is, the levitation).) the analytical expression between the position coordinates and the direction of the artificial magnetic field, and introduce a suitable dimensionless the position equation of the equilibrium point, and then obtain the direction of the artificial magnetic field corresponding to any floating position, and give the required direction of the artificial magnetic field. The amount of current required in a superconducting coil. The method only needs to adjust the magnitude of the currents in the three orthogonal superconducting coils on the main star to obtain any direction of the artificial magnetic field, and to achieve the required levitation task at the equilibrium point. The electric charge on the fuselage can further adjust the suspension position without consuming additional chemical fuel, which has application prospects in the space observation mission of close suspension.

The required charge amount is as follows:
it should be noted that, changing the charged amount of the charged slave star can only change the floating distance, but not change the floating direction vector, i.e. new floating coordinate

A Lorentz force levitation method based on artificial magnetic field, comprising the following steps:

Step 1: Establish the motion equation of the charged slave star under the action of the artificial magnetic field whose direction is adjustable on the master star.

The main star runs on the Earth's high orbit, and the charged secondary star will not be disturbed by the earth's magnetic field. The artificial magnetic field on the main star generates Lorentz force on the secondary star, and the artificial magnetic field on the main star spins, and the direction is adjustable; Lorentz The force is used to achieve levitation of the charged slave star relative to the master star. The motion equation of the charged secondary star in the local horizontal local vertical coordinate system with the primary star as the origin is expressed as,

$$\begin{cases} \ddot{x} - 2n\dot{y} - 3n^2x = f_x \\ \ddot{y} + 2n\dot{x} = f_y \\ \ddot{z} + n^2z = f_z \end{cases} \quad (1)^{\top}$$

$$\begin{cases} \ddot{x} - 2n\dot{y} - 3n^2x = f_x \\ \ddot{y} + 2n\dot{x} = f_y \\ \ddot{z} + n^2z = f_z \end{cases} \quad (1)^{\top} \circ$$

$$\boldsymbol{r} = (x, y, z)^{\top};$$

带电从星的速度向量

$$\dot{\boldsymbol{r}} = (\dot{x}, \dot{y}, \dot{z})^{\top};$$

n 为主星绕地球运动的平均角速度。

$$\boldsymbol{f}_L = (f_x, f_y, f_z)^{\top}$$

为带电从星所受的洛伦兹力， where, the position vector of the charged slave star

$$\mathbf{r} = (x, y, z)^{\top};$$

Velocity vector of charged slave stars

$$\dot{\mathbf{r}} = (\dot{x}, \dot{y}, \dot{z})^{\top};$$

n The average angular velocity of the primary star moving around the Earth.

$$\mathbf{f}_L = (f_x, f_y, f_z)^{\top}$$

for the Lorentz force from the charged stars,

$$\mathbf{f}_L = \frac{q}{m} \mathbf{v}_r \times \mathbf{B} = \frac{q}{m} \cdot (\dot{\mathbf{r}} - \boldsymbol{\omega}_c \times \mathbf{r}) \times \mathbf{B} \quad (2)$$

$$\mathbf{f}_L = \frac{q}{m} \mathbf{v}_r \times \mathbf{B} = \frac{q}{m} \cdot (\dot{\mathbf{r}} - \boldsymbol{\omega}_c \times \mathbf{r}) \times \mathbf{B} \quad (2)$$



为带电从星的荷质比， v_r 为带电从星相对于主星的速度， ω_c 为主星上人工磁场的角速度； B 为人工磁场的强度，定义为in,

q

m

is the charge-to-mass ratio of the charged slave star, v_r is the velocity of the charged slave star relative to the master star, ω_c is the angular velocity of the artificial magnetic field on the master star; B is the strength of the artificial magnetic field, defined as

$$\boldsymbol{B} = \frac{B_0}{r^2} \nabla \times (\boldsymbol{N} \times \boldsymbol{r}) \quad (3)$$

$$\boldsymbol{B} = \frac{B_0}{r^2} \nabla \times (\boldsymbol{N} \times \boldsymbol{r}) \quad (3)$$

$$\boldsymbol{N} = [N_x, N_y, N_z]^T$$

为人工磁场的方向，而角速度可以表示为

$$\boldsymbol{\omega}_c = \omega_c [N_x, N_y, N_z]^{\top},$$

ω_c 为角速度的大小； B_0 是磁通量，

$$r = \sqrt{x^2 + y^2 + z^2}$$

为从星相对于主星的距离。In the formula,

$$\boldsymbol{N} = [N_x, N_y, N_z]^{\top}$$

is the direction of the artificial magnetic field, and the angular velocity can be expressed as

$$\boldsymbol{\omega}_c = \omega_c [N_x, N_y, N_z]^{\top},$$

ω_c is the magnitude of the angular velocity; B_0 is the magnetic flux,

$$r = \sqrt{x^2 + y^2 + z^2}$$

is the distance of the secondary star relative to the primary star.

Expanding the three components of the Lorentz force in equation (2), we get,

$$\left\{ \begin{aligned}
f_x &= \frac{q}{m} \frac{B_0}{r^3} \left[\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} (\dot{y}z - \dot{z}y) - \omega_c (xN_z - zN_x) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} z - N_z \right) \right. \\
&\quad \left. + \dot{z}N_y - \dot{y}N_z + \omega_c (yN_x - xN_y) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} y - N_y \right) \right] \\
f_y &= \frac{q}{m} \frac{B_0}{r^3} \left[\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} (\dot{z}x - \dot{x}z) - \omega_c (yN_x - xN_y) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} x - N_x \right) \right. \\
&\quad \left. + \dot{x}N_z - \dot{z}N_x + \omega_c (zN_y - yN_z) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} z - N_z \right) \right] \\
f_z &= \frac{q}{m} \frac{B_0}{r^3} \left[\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} (\dot{x}y - \dot{y}x) - \omega_c (zN_y - yN_z) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} y - N_y \right) \right. \\
&\quad \left. + \dot{y}N_x - \dot{x}N_y + \omega_c (xN_z - zN_x) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} x - N_x \right) \right]
\end{aligned} \right. \quad (4)$$

$$\left\{ \begin{aligned}
f_x &= \frac{q}{m} \frac{B_0}{r^3} \left[\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} (\dot{y}z - \dot{z}y) - \omega_c (xN_z - zN_x) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} z - N_z \right) \right. \\
&\quad \left. + \dot{z}N_y - \dot{y}N_z + \omega_c (yN_x - xN_y) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} y - N_y \right) \right] \\
f_y &= \frac{q}{m} \frac{B_0}{r^3} \left[\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} (\dot{z}x - \dot{x}z) - \omega_c (yN_x - xN_y) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} x - N_x \right) \right. \\
&\quad \left. + \dot{x}N_z - \dot{z}N_x + \omega_c (zN_y - yN_z) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} z - N_z \right) \right] \\
f_z &= \frac{q}{m} \frac{B_0}{r^3} \left[\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} (\dot{x}y - \dot{y}x) - \omega_c (zN_y - yN_z) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} y - N_y \right) \right. \\
&\quad \left. + \dot{y}N_x - \dot{x}N_y + \omega_c (xN_z - zN_x) \left(\frac{3\mathbf{N} \cdot \mathbf{r}}{r^2} x - N_x \right) \right]
\end{aligned} \right. \quad (4)$$

Further expanding the components of the Lorentz force in formula (4), we get

$$\begin{aligned}
f_x &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{y} \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] + N_y \dot{z}(x^2 + z^2 - 2y^2) \right. \\
&\quad - 3y\dot{z}(xN_x + zN_z) - \omega_c(xN_y - yN_x) \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] \\
&\quad \left. - \omega_c(xN_z - zN_x) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right\} \\
f_y &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{x} \left[-3z(xN_x + yN_y) + N_z(x^2 + y^2 - 2z^2) \right] - N_x \dot{z}(y^2 + z^2 - 2x^2) \right. \\
&\quad + 3x\dot{z}(yN_y + zN_z) + \omega_c(yN_x - xN_y) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\
&\quad \left. + \omega_c(yN_z - zN_y) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right\} \quad (5) \\
f_z &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{x} \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] + N_x \dot{y}(y^2 + z^2 - 2x^2) \right. \\
&\quad - 3x\dot{y}(yN_y + zN_z) - \omega_c(zN_x - xN_z) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\
&\quad \left. - \omega_c(zN_y - yN_z) \left[3y(xN_z + zN_x) - N_y(x^2 + z^2 - 2y^2) \right] \right\} \\
f_x &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{y} \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] + N_y \dot{z}(x^2 + z^2 - 2y^2) \right. \\
&\quad - 3y\dot{z}(xN_x + zN_z) - \omega_c(xN_y - yN_x) \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] \\
&\quad \left. - \omega_c(xN_z - zN_x) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right\} \\
f_y &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{x} \left[-3z(xN_x + yN_y) + N_z(x^2 + y^2 - 2z^2) \right] - N_x \dot{z}(y^2 + z^2 - 2x^2) \right. \\
&\quad + 3x\dot{z}(yN_y + zN_z) + \omega_c(yN_x - xN_y) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\
&\quad \left. + \omega_c(yN_z - zN_y) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right\} \quad (5) \\
f_z &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{x} \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] + N_x \dot{y}(y^2 + z^2 - 2x^2) \right. \\
&\quad - 3x\dot{y}(yN_y + zN_z) - \omega_c(zN_x - xN_z) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\
&\quad \left. - \omega_c(zN_y - yN_z) \left[3y(xN_z + zN_x) - N_y(x^2 + z^2 - 2y^2) \right] \right\}
\end{aligned}$$

Step 2: Determine the equilibrium point position equation of the relative motion equation of the slave star under the action of the master star's adjustable artificial magnetic field.

$$\dot{x} = \dot{y} = \dot{z} = 0, \ddot{x} = \ddot{y} = \ddot{z} = 0,$$

得到平衡点位置方程如下, The suspended position is the point at which the slave star is stationary relative to the master star, that is, the equilibrium point of the relative motion equation (1), let

$$\dot{x} = \dot{y} = \dot{z} = 0, \ddot{x} = \ddot{y} = \ddot{z} = 0,$$

The position equation of the equilibrium point is obtained as follows,

$$\left\{ \begin{array}{l} 3n^2x + \frac{q}{m} \frac{B_0 \omega_c}{r^5} \left\{ (zN_x - xN_z) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right. \\ \quad \left. + (yN_x - xN_y) \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] \right\} \\ \quad (yN_x - xN_y) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\ \quad + (zN_y - yN_z) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \end{array} \right. = 0 \\ n^2z + \frac{q}{m} \frac{B_0 \omega_c}{r^5} \left\{ (zN_y - yN_z) \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] \right. \\ \quad \left. + (xN_z - zN_x) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \right\} = 0 \end{array} \right. = 0 \quad (6)$$

$$\left\{ \begin{array}{l} 3n^2x + \frac{q}{m} \frac{B_0 \omega_c}{r^5} \left\{ (zN_x - xN_z) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right. \\ \quad \left. + (yN_x - xN_y) \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] \right\} \\ \quad (yN_x - xN_y) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\ \quad + (zN_y - yN_z) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \end{array} \right. = 0 \\ n^2z + \frac{q}{m} \frac{B_0 \omega_c}{r^5} \left\{ (zN_y - yN_z) \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] \right. \\ \quad \left. + (xN_z - zN_x) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \right\} = 0 \end{array} \right. = 0 \quad (6)$$

At the equilibrium point of the equation of motion, the Earth's gravitational force on the charged secondary star cancels out the Lorentz force from the artificial magnetic field, so the secondary star is stationary relative to the primary star, that is, the relative position between the primary and secondary stars remains unchanged, while the relative position of the secondary star remains unchanged. Velocity and relative acceleration are both zero.

Step 3: Perform dimensionless processing on the formula (6) in Step 2.

$$a^{\star}=\left|\frac{B_0}{n}\frac{q}{m}\frac{1}{\beta}\right|^{1/3},$$

$\beta = n/\omega_c$ 为角速度的比值，对方程(6)进行无量纲化处理，记无量纲的位置坐标为

$$[X,Y,Z]^{\top}=[x,y,z]^{\top}/a^{\star},$$

则得到无量纲的运动方程的平衡点位置方程为：Introduce unit length

$$a^{\star}=\left|\frac{B_0}{n}\frac{q}{m}\frac{1}{\beta}\right|^{1/3},$$

$\beta = n/\omega_c$ is the ratio of the angular velocity, and the dimensionless processing of equation (6) is performed, and the dimensionless position coordinates are recorded as

$$[X,Y,Z]^{\top}=[x,y,z]^{\top}/a^{\star},$$

Then the equilibrium point position equation of the dimensionless motion equation is obtained as:

$$\begin{cases}
3X + \frac{1}{R^5} \left\{ (ZN_X - XN_Z) \left[3Z(XN_X + YN_Y) - N_Z(X^2 + Y^2 - 2Z^2) \right] \right. \\
\quad \left. + (YN_X - XN_Y) \left[3Y(XN_X + ZN_Z) - N_Y(X^2 + Z^2 - 2Y^2) \right] \right\} \\
\quad (YN_X - XN_Y) \left[3X(YN_Y + ZN_Z) - N_X(Y^2 + Z^2 - 2X^2) \right] \\
\quad - (ZN_Y - YN_Z) \left[3Z(XN_X + YN_Y) - N_Z(X^2 + Y^2 - 2Z^2) \right] \\
Z + \frac{1}{R^5} \left\{ (ZN_Y - YN_Z) \left[3Y(XN_X + ZN_Z) - N_Y(X^2 + Z^2 - 2Y^2) \right] \right. \\
\quad \left. + (XN_Z - ZN_X) \left[3X(YN_Y + ZN_Z) - N_X(Y^2 + Z^2 - 2X^2) \right] \right\} \\
3X + \frac{1}{R^5} \left\{ (ZN_X - XN_Z) \left[3Z(XN_X + YN_Y) - N_Z(X^2 + Y^2 - 2Z^2) \right] \right. \\
\quad \left. + (YN_X - XN_Y) \left[3Y(XN_X + ZN_Z) - N_Y(X^2 + Z^2 - 2Y^2) \right] \right\} \\
\quad (YN_X - XN_Y) \left[3X(YN_Y + ZN_Z) - N_X(Y^2 + Z^2 - 2X^2) \right] \\
\quad - (ZN_Y - YN_Z) \left[3Z(XN_X + YN_Y) - N_Z(X^2 + Y^2 - 2Z^2) \right] \\
Z + \frac{1}{R^5} \left\{ (ZN_Y - YN_Z) \left[3Y(XN_X + ZN_Z) - N_Y(X^2 + Z^2 - 2Y^2) \right] \right. \\
\quad \left. + (XN_Z - ZN_X) \left[3X(YN_Y + ZN_Z) - N_X(Y^2 + Z^2 - 2X^2) \right] \right\}
\end{cases} = 0 \quad (7)$$

$$R = \sqrt{X^2 + Y^2 + Z^2}$$

为带电从星与主星之间无量纲的距离，

$$[N_X, N_Y, N_Z]^T = [N_x, N_y, N_z]^T$$

为人工磁场的单位方向分量，大写下标是为了与无量纲坐标

$$[X,Y,Z]^{\top}$$

保持统一。in,

$$R=\sqrt{X^2+Y^2+Z^2}$$

is the dimensionless distance between the charged secondary star and the host star,

$$[N_X,N_Y,N_Z]^{\top}=[N_x,N_y,N_z]^{\top}$$

is the unit directional component of the artificial magnetic field, and the capitalized subscript is to be related to the dimensionless coordinate

$$[X,Y,Z]^{\top}$$

Stay unified.

$$[X_0,Y_0,Z_0]^{\top},$$

确定主星上人工磁场的方向。Step 4. According to the given dimensionless suspension position constraint

$$[X_0, Y_0, Z_0]^T,$$

Determine the orientation of the artificial magnetic field on the host star.

$$[X_0, Y_0, Z_0]^T,$$

也即平衡点的位置坐标为

$$[X_0, Y_0, Z_0]^T,$$

代入方程(7)并求解可得人工磁场的单位方向分量为：The dimensionless coordinates of the floating position in the actual task are

$$[X_0, Y_0, Z_0]^T,$$

That is, the position coordinates of the equilibrium point are

$$[X_0, Y_0, Z_0]^T,$$

Substitute into equation (7) and solve to obtain the unit directional component of the artificial magnetic field as:

$$\left\{ \begin{array}{l} N_x = \sigma \sqrt{\frac{X_0^2 [5Y_0^2 Z_0^2 + 8Z_0^4 - X_0^2 (27Y_0^2 + 40Z_0^2)]^2}{4R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \\ N_y = \sigma \zeta \frac{-Y_0 [-18X_0^4 + Z_0^2 (Y_0^2 - 2Z_0^2) + X_0^2 (9Y_0^2 + 28Z_0^2)]}{2\sqrt{R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \\ N_z = \sigma \zeta \frac{-3Z_0 [-8X_0^4 + Y_0^2 Z_0^2 + X_0^2 (Y_0^2 + 8Z_0^2)]}{2\sqrt{R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \end{array} \right. \quad (8)$$

$$\left\{ \begin{array}{l} N_x = \sigma \sqrt{\frac{X_0^2 [5Y_0^2 Z_0^2 + 8Z_0^4 - X_0^2 (27Y_0^2 + 40Z_0^2)]^2}{4R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \\ N_y = \sigma \zeta \frac{-Y_0 [-18X_0^4 + Z_0^2 (Y_0^2 - 2Z_0^2) + X_0^2 (9Y_0^2 + 28Z_0^2)]}{2\sqrt{R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \\ N_z = \sigma \zeta \frac{-3Z_0 [-8X_0^4 + Y_0^2 Z_0^2 + X_0^2 (Y_0^2 + 8Z_0^2)]}{2\sqrt{R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \end{array} \right. \quad (8)$$

$$R_0 = \sqrt{X_0^2 + Y_0^2 + Z_0^2} ;$$

ζ为式

$$X_0 [5Y_0^2 Z_0^2 + 8Z_0^4 - X_0^2 (27Y_0^2 + 40Z_0^2)]$$

符号函数，定义为In the formula,

$$R_0 = \sqrt{X_0^2 + Y_0^2 + Z_0^2} ;$$

ζ is the formula

$$X_0[5Y_0^2Z_0^2 + 8Z_0^4 - X_0^2(27Y_0^2 + 40Z_0^2)]$$

symbolic function, defined as

$$\zeta = \begin{cases} 1, & \text{if } X_0[5Y_0^2Z_0^2 + 8Z_0^4 - X_0^2(27Y_0^2 + 40Z_0^2)] \geq 0 \\ -1, & \text{if } X_0[5Y_0^2Z_0^2 + 8Z_0^4 - X_0^2(27Y_0^2 + 40Z_0^2)] < 0 \end{cases} \quad (9)$$

$$\zeta = \begin{cases} 1, & \text{if } X_0[5Y_0^2Z_0^2 + 8Z_0^4 - X_0^2(27Y_0^2 + 40Z_0^2)] \geq 0 \\ -1, & \text{if } X_0[5Y_0^2Z_0^2 + 8Z_0^4 - X_0^2(27Y_0^2 + 40Z_0^2)] < 0 \end{cases} \quad (9)$$

$$Z_0^2 - 3X_0^2 > 0,$$

也即

$$|Z_0| > \sqrt{3} |X_0|;$$

当 $X_0 = 0$ 时，则没有以上约束条件。In addition, the value of σ can be 1 or -1, which means that for any given suspended position $[X_0, Y_0, Z_0]^T$, there are two possible artificial magnetic field directions, namely two sets of solutions; and the two directions are opposite. It should be noted that in order to ensure that N_x , N_y and N_z are all real numbers, the components of the dimensionless coordinates must satisfy: when $X_0 \neq 0$,

$$Z_0^2 - 3X_0^2 > 0,$$

that is

$$|Z_0| > \sqrt{3} |X_0|;$$

When $X_0 = 0$, the above constraints do not exist.

$$[x_0, y_0, z_0]^T$$

的悬浮所需的电流大小。 Step 5: Determine any actual relative position based on the directional component of the artificial magnetic field solved in Step 4

$$[x_0, y_0, z_0]^T$$

The amount of current required for the suspension.

Since the artificial magnetic field on the main star is composed of three orthogonal high-temperature superconducting coils, artificial magnetic fields with different orientations can be obtained by adjusting the current in the superconducting coils. The relationship between the magnetic flux and the parameters of the superconducting coil is as follows

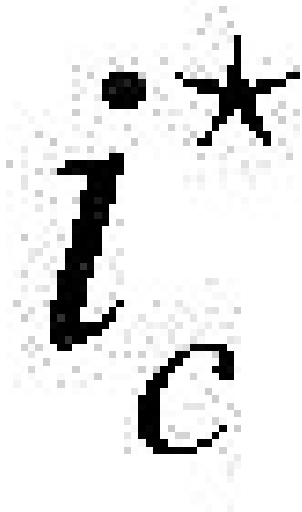
$$B_0 = \frac{\mu_0}{4\pi} n_c i_c \pi r_c^2 \quad (10)$$

$$B_0 = \frac{\mu_0}{4\pi} n_c i_c \pi r_c^2 \quad (10)$$

Among them, $\mu_0 = 4\pi \times 10^{-7} \text{ N/A}^2$ is the vacuum permeability, n_c is the number of turns of the coil, i_c is the current intensity, and r_c is the radius of the coil.



为标称电流大小，结合公式(8)，得到三个线圈中的电流分别为The three superconducting coils have the same number of turns and radii, and the magnetic fields in different directions can be achieved by adjusting the current in the coils. remember



is the nominal current, combined with formula (8), the currents in the three coils are obtained as

$$\begin{cases} i_x = i_c^* N_x \\ i_y = i_c^* N_y \\ i_z = i_c^* N_z \end{cases} \quad (11)$$

$$\begin{cases} i_x = i_c^* N_x \\ i_y = i_c^* N_y \\ i_z = i_c^* N_z \end{cases} \quad (11)$$

In the formula, i_x , i_y and i_z correspond to the magnitude of the current in the superconducting coil along the x-axis, y-axis and z-axis, respectively.

$$[X_0, Y_0, Z_0]^T$$

的悬浮所需的电流大小。Formulas (8) and (11) jointly give a specific magnetic flux B_0 , for a given number of turns and a radius of the superconducting coil, the dimensionless relative position is

$$[X_0, Y_0, Z_0]^T$$

The amount of current required for the suspension.

$$[x_0, y_0, z_0]^T,$$

则需要将其无量纲化得到对应的无量纲坐标

$$[X_0, Y_0, Z_0]^T,$$

才能利用步骤四求得三个线圈中所需电流的大小。具体方法如下：首先，根据标称电流 i_c 和线圈参数 $n_c r_c$ ，利用公式(10)计算出磁通量 B_0 ；接下来，基于给定的荷质比

q

m

和角速度比值 β ，计算出单位长度

$$a^{\star} = \left| \frac{B_0}{n} \frac{q}{m} \frac{1}{\beta} \right|^{1/3}$$

的值，进而将实际的悬浮位置坐标

$$[x_0, y_0, z_0]^T$$

转化成无量纲的位置坐标

$$[X_0, Y_0, Z_0]^T$$

；最后，利用公式(8)求解出 N_x, N_y, N_z 的值，并带入公式(11)即可得到所需的电流大小

$$[i_x, i_y, i_z]^T$$

，从而实现任意的实际位置

$$[x_0, y_0, z_0]^T$$

的悬浮。For a given actual floating position coordinate

$$[x_0, y_0, z_0]^T,$$

Then it needs to be dimensionless to get the corresponding dimensionless coordinates

$$[X_0, Y_0, Z_0]^T,$$

Step 4 can be used to obtain the required current in the three coils. The specific method is as follows: first, according to the nominal current i_c and the coil parameters n_c, r_c , use the formula (10) to calculate the magnetic flux B_0 ; next, based on the given charge-to-mass ratio

$$\frac{q}{m}$$

$$m$$

and angular velocity ratio β , calculate the unit length

$$a^{\star} = \left| \frac{B_0}{n} \frac{q}{m} \frac{1}{\beta} \right|^{1/3}$$

The value of $a^{\star}$, and then the actual floating position coordinates

$$[x_0, y_0, z_0]^T$$

Convert to dimensionless position coordinates

$$[X_0, Y_0, Z_0]^T$$

Finally, use formula (8) to solve the value of N_x, N_y, N_z , and bring it into formula (11) to get the required current size

$$[i_x, i_y, i_z]^T$$

, so as to achieve any actual position

$$[x_0, y_0, z_0]^T$$

suspension.

By changing the levitating position from the star's charge:

Based on the magnitude of the current obtained in step 5, the floating position can be further changed by adjusting the charge amount of the charged slave star.



来确定单位长度的，因此在保持参数 n 和 β 的值不变时，能够通过改变带电从星的带电量 q ，来实现不同位置的悬浮。实际的电量与新的悬浮位置之间的关系如下Since step five is based on the given

$$\underline{q}$$

$$m$$

to determine the unit length, so while keeping the values of the parameters n and β unchanged, the levitation at different positions can be achieved by changing the charge amount q of the charged slave star. The relationship between the actual charge and the new floating position is as follows

$$q = q_0 \left(\frac{ds}{ds_0} \right)^3 \tag{12}$$

$$q = q_0 \left(\frac{ds}{ds_0} \right)^3 \tag{12}$$

$$[x_0, y_0, z_0]^T$$

(对应悬浮距离为

$$ds_0 = \sqrt{x_0^2 + y_0^2 + z_0^2} \quad)$$

时的标称带电量，q为新的悬浮坐标为

$$[x_1, y_1, z_1]^T$$

(对应悬浮距离为

$$ds = \sqrt{x_1^2 + y_1^2 + z_1^2} \quad)$$

下所需的带电量。Among them, q₀ is the floating coordinate of

$$[x_0, y_0, z_0]^T$$

(The corresponding suspension distance is

$$ds_0 = \sqrt{x_0^2 + y_0^2 + z_0^2} \quad)$$

When the nominal charge, q is the new suspension coordinate is

$$[x_1, y_1, z_1]^T$$

(The corresponding suspension distance is

$$ds = \sqrt{x_1^2 + y_1^2 + z_1^2})$$

the required charge.

$$[x_1, y_1, z_1]^T$$

与原坐标

$$[x_0, y_0, z_0]^T$$

同向，且满足

$$[x_1, y_1, z_1]^T = \sqrt{\frac{ds}{ds_0}} [x_0, y_0, z_0]^T。$$

It should be noted that changing the charge amount of the charged slave star here can only change the distance of the suspension, but not the direction vector of the suspension, that is, the new suspension coordinates.

$$[x_1, y_1, z_1]^T$$

with the original coordinates

$$[x_0, y_0, z_0]^T$$

in the same direction and satisfy

$$[x_1, y_1, z_1]^T = \sqrt{\frac{ds}{ds_0}} [x_0, y_0, z_0]^T \circ$$

Beneficial effects:

A Lorentz force levitation method based on artificial magnetic field

1. A Lorentz force levitation method based on an artificial magnetic field disclosed in the present invention, by adjusting the current size of the three superconducting coils of the artificial magnetic field on the main star, an arbitrary artificial magnetic field direction can be obtained, thereby obtaining the balance of any coordinate point, and finally realize the suspension of the charged slave star at any position relative to the master star.

2. A Lorentz force levitation method based on an artificial magnetic field disclosed in the present invention utilizes the Lorentz force generated by the artificial magnetic field on the master star to the charged slave star to achieve suspension, that is, the master and slave stars are levitated by the Lorentz force. The given relative position remains unchanged during the time, so there is no need to consume traditional chemical fuel, so no chemical pollution is generated, and it is suitable for satellites with photosensitive loads such as cameras.

3. A Lorentz force levitation method based on an artificial magnetic field disclosed in the present invention can adjust the levitation position by changing the charged amount of the slave star while keeping the levitation relative position vector direction unchanged.

4. The artificial magnetic field-based Lorentz force levitation method disclosed in the present invention has

great application prospects in close-range levitation, long-term space observation tasks, etc. due to the above-mentioned beneficial effects.

Description of drawings

Fig. 1 is the flow chart of a kind of Lorentz force levitation method based on artificial magnetic field of the present invention;

2 is a schematic diagram of three orthogonal high temperature superconducting coils of the present invention;

FIG. 3 is a schematic diagram of the suspension mission of the present invention located in the high orbit of the earth.

Detailed ways

The present invention will be further described below with reference to the accompanying drawings and specific embodiments.

Example 1:

The Lorentz force levitation method based on an artificial magnetic field disclosed in this embodiment, considering the task of long-term tracking and observation of a spacecraft in a geosynchronous orbit (orbit radius of 42,164 km), can), such as a position of 1km, deploy a charged slave star to achieve suspension, so as to achieve the purpose of continuous tracking and monitoring of the master star. In traditional levitation missions, chemical propellants need to be consumed all the time to achieve the suspension of the slave star relative to the master star. In this example, only the slave star needs to be charged, and the artificial magnetic field of a specific direction can be obtained by adjusting the current in the superconducting coil on the master star. Suspension can be achieved at any position. Specific steps are as follows:

Step 1. Establish the motion equation of the charged slave star under the action of the earth's gravitational force and the artificial magnetic field of the master star. The orbit of the master star is a geosynchronous orbit, so the disturbance of the earth's magnetic field to the charged slave star can be ignored. The charged secondary star is only affected by the combined influence of gravity and the Lorentz force generated by the artificial magnetic field on the primary star, and its motion equation in the local horizontal and local vertical coordinate system with the primary star as the origin is expressed as,

$$\begin{cases} \ddot{x} - 2n\dot{y} - 3n^2x = f_x \\ \ddot{y} + 2n\dot{x} = f_y \\ \ddot{z} + n^2z = f_z \end{cases} \quad (13)$$

$$\begin{cases} \ddot{x} - 2n\dot{y} - 3n^2x = f_x \\ \ddot{y} + 2n\dot{x} = f_y \\ \ddot{z} + n^2z = f_z \end{cases} \quad (13)$$

$$\boldsymbol{f}_L = (f_x, f_y, f_z)^\top$$

为带电从星所受的洛伦兹力，In the formula, $n=7.2922\times10^{-5}$ rad/s The average angular velocity of the geosynchronous orbit where the main star is located,

$$\boldsymbol{f}_L = (f_x, f_y, f_z)^\top$$

for the Lorentz force from the charged stars,

$$\boldsymbol{f}_L = \frac{q}{m} \cdot (\dot{\boldsymbol{r}} - \boldsymbol{\omega}_c \times \boldsymbol{r}) \times \boldsymbol{B} \quad (14)$$

$$\boldsymbol{f}_L = \frac{q}{m} \cdot (\dot{\boldsymbol{r}} - \boldsymbol{\omega}_c \times \boldsymbol{r}) \times \boldsymbol{B} \quad (14)$$

$$\frac{q}{m}$$

$$m$$

为带电从星的荷质比， v_r 为带电从星相对于主星的速度， ω_c 为主星上自旋磁场的角速度；记

$$\boldsymbol{N}=[N_x,N_y,N_z]^{\top}$$

为磁场的方向， B_0 是磁通量，人工磁场的强度定义为

$$\boldsymbol{B}=\frac{B_0}{r^2}\nabla\times(\boldsymbol{N}\times\boldsymbol{r})\,.$$

in,

$$\frac{q}{m}$$

$$m$$

is the charge-to-mass ratio of the charged slave star, v_r is the velocity of the charged slave star relative to the master star, ω_c is the angular velocity of the spin magnetic field on the master star;

$$\mathbf{N} = [N_x, N_y, N_z]^T$$

is the direction of the magnetic field, B_0 is the magnetic flux, and the strength of the artificial magnetic field is defined as

$$\mathbf{B} = \frac{B_0}{r^2} \nabla \times (\mathbf{N} \times \mathbf{r}).$$

Expanding the three components in equation (2), we get,

$$\begin{aligned}
f_x &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{y} \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] + N_y \dot{z}(x^2 + z^2 - 2y^2) \right. \\
&\quad - 3y\dot{z}(xN_x + zN_z) - \omega_c(xN_y - yN_x) \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] \\
&\quad \left. - \omega_c(xN_z - zN_x) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right\} \\
f_y &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{x} \left[-3z(xN_x + yN_y) + N_z(x^2 + y^2 - 2z^2) \right] - N_x \dot{z}(y^2 + z^2 - 2x^2) \right. \\
&\quad + 3x\dot{z}(yN_y + zN_z) + \omega_c(yN_x - xN_y) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\
&\quad \left. + \omega_c(yN_z - zN_y) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right\} \tag{15}
\end{aligned}$$

$$\begin{aligned}
f_z &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{x} \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] + N_x \dot{y}(y^2 + z^2 - 2x^2) \right. \\
&\quad - 3x\dot{y}(yN_y + zN_z) - \omega_c(zN_x - xN_z) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\
&\quad \left. - \omega_c(zN_y - yN_z) \left[3y(xN_z + zN_x) - N_y(x^2 + z^2 - 2y^2) \right] \right\} \\
f_x &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{y} \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] + N_y \dot{z}(x^2 + z^2 - 2y^2) \right. \\
&\quad - 3y\dot{z}(xN_x + zN_z) - \omega_c(xN_y - yN_x) \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] \\
&\quad \left. - \omega_c(xN_z - zN_x) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right\} \\
f_y &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{x} \left[-3z(xN_x + yN_y) + N_z(x^2 + y^2 - 2z^2) \right] - N_x \dot{z}(y^2 + z^2 - 2x^2) \right. \\
&\quad + 3x\dot{z}(yN_y + zN_z) + \omega_c(yN_x - xN_y) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\
&\quad \left. + \omega_c(yN_z - zN_y) \left[3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2) \right] \right\} \tag{15}
\end{aligned}$$

$$\begin{aligned}
f_z &= \frac{q}{m} \frac{B_0}{r^5} \left\{ \dot{x} \left[3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2) \right] + N_x \dot{y}(y^2 + z^2 - 2x^2) \right. \\
&\quad - 3x\dot{y}(yN_y + zN_z) - \omega_c(zN_x - xN_z) \left[3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2) \right] \\
&\quad \left. - \omega_c(zN_y - yN_z) \left[3y(xN_z + zN_x) - N_y(x^2 + z^2 - 2y^2) \right] \right\}
\end{aligned}$$

$$r = \sqrt{x^2 + y^2 + z^2}$$

为带电从星相对于主星的距离。in,

$$r = \sqrt{x^2 + y^2 + z^2}$$

is the distance of the charged secondary star relative to the primary star.

$$\dot{x} = \dot{y} = \dot{z} = 0, \ddot{x} = \ddot{y} = \ddot{z} = 0,$$

可以得到Step 2. Determine the position equation of the equilibrium point, that is, let equation (13) in

$$\dot{x} = \dot{y} = \dot{z} = 0, \ddot{x} = \ddot{y} = \ddot{z} = 0,$$

can get

$$\left\{ \begin{array}{l} 3n^2x + \frac{q}{m} \frac{B_0 \omega_c}{r^5} \left\{ (zN_x - xN_z) [3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2)] \right. \\ \quad \left. + (yN_x - xN_y) [3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2)] \right\} \\ \quad (yN_x - xN_y) [3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2)] \\ \quad \left. + (zN_y - yN_z) [3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2)] \right\} = 0 \\ n^2z + \frac{q}{m} \frac{B_0 \omega_c}{r^5} \left\{ (zN_y - yN_z) [3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2)] \right. \\ \quad \left. + (xN_z - zN_x) [3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2)] \right\} = 0 \end{array} \right. = 0 \quad (16)$$

$$\left\{ \begin{array}{l} 3n^2x + \frac{q}{m} \frac{B_0 \omega_c}{r^5} \left\{ (zN_x - xN_z) [3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2)] \right. \\ \quad \left. + (yN_x - xN_y) [3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2)] \right\} \\ \quad (yN_x - xN_y) [3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2)] \\ \quad \left. + (zN_y - yN_z) [3z(xN_x + yN_y) - N_z(x^2 + y^2 - 2z^2)] \right\} = 0 \\ n^2z + \frac{q}{m} \frac{B_0 \omega_c}{r^5} \left\{ (zN_y - yN_z) [3y(xN_x + zN_z) - N_y(x^2 + z^2 - 2y^2)] \right. \\ \quad \left. + (xN_z - zN_x) [3x(yN_y + zN_z) - N_x(y^2 + z^2 - 2x^2)] \right\} = 0 \end{array} \right. = 0 \quad (16)$$

Step 3: Perform dimensionless processing on the formula (16) of Step 2.

$$a^{\star} = \left| \frac{B_0}{n} \frac{q}{m} \frac{1}{\beta} \right|^{1/3},$$

并定义无量纲的坐标

$$[X, Y, Z]^{\top} = [x, y, z]^{\top} / a^{\star}$$

, 那么平衡点的位置方程(16)可以表示成无量纲的形式: Introduce unit length

$$a^{\star} = \left| \frac{B_0}{n} \frac{q}{m} \frac{1}{\beta} \right|^{1/3},$$

and define dimensionless coordinates

$$[X, Y, Z]^{\top} = [x, y, z]^{\top} / a^{\star}$$

, then the position equation (16) of the equilibrium point can be expressed in a dimensionless form:

$$\begin{cases}
3X + \frac{1}{R^5} \left\{ (ZN_X - XN_Z) \left[3Z(XN_X + YN_Y) - N_Z(X^2 + Y^2 - 2Z^2) \right] \right. \\
\quad \left. + (YN_X - XN_Y) \left[3Y(XN_X + ZN_Z) - N_Y(X^2 + Z^2 - 2Y^2) \right] \right\} \\
\quad (YN_X - XN_Y) \left[3X(YN_Y + ZN_Z) - N_X(Y^2 + Z^2 - 2X^2) \right] \\
\quad - (ZN_Y - YN_Z) \left[3Z(XN_X + YN_Y) - N_Z(X^2 + Y^2 - 2Z^2) \right] \\
\quad \left. + (XN_Z - ZN_X) \left[3X(YN_Y + ZN_Z) - N_X(Y^2 + Z^2 - 2X^2) \right] \right\} = 0 \\
Z + \frac{1}{R^5} \left\{ (ZN_Y - YN_Z) \left[3Y(XN_X + ZN_Z) - N_Y(X^2 + Z^2 - 2Y^2) \right] \right. \\
\quad \left. + (XN_Z - ZN_X) \left[3X(YN_Y + ZN_Z) - N_X(Y^2 + Z^2 - 2X^2) \right] \right\} = 0
\end{cases} \quad (17)$$

$$r = \sqrt{x^2 + y^2 + z^2}$$

为带电从星相对于主星的距离。in,

$$r = \sqrt{x^2 + y^2 + z^2}$$

is the distance of the charged secondary star relative to the primary star.

$$[X_0, Y_0, Z_0]^T$$

，确定主星上人工磁场的方向。Step 4. According to the given dimensionless suspension position constraint

$$[X_0, Y_0, Z_0]^T$$

, to determine the direction of the artificial magnetic field on the host star.

$$[X_0, Y_0, Z_0]^T$$

，也即方程(17)中的平衡点坐标为

$$[X_0, Y_0, Z_0]^T$$

，代入可求得人工磁场的单位方向分量为Given a dimensionless floating position

$$[X_0, Y_0, Z_0]^T$$

, that is, the coordinates of the equilibrium point in equation (17) are

$$[X_0, Y_0, Z_0]^T$$

, the unit direction component of the artificial magnetic field can be obtained by substituting it as

$$\begin{cases} N_x = \sigma \sqrt{\frac{X_0^2 [5Y_0^2 Z_0^2 + 8Z_0^4 - X_0^2 (27Y_0^2 + 40Z_0^2)]^2}{4R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \\ N_y = \sigma \zeta \frac{-Y_0 [-18X_0^4 + Z_0^2 (Y_0^2 - 2Z_0^2) + X_0^2 (9Y_0^2 + 28Z_0^2)]}{2\sqrt{R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \\ N_z = \sigma \zeta \frac{-3Z_0 [-8X_0^4 + Y_0^2 Z_0^2 + X_0^2 (Y_0^2 + 8Z_0^2)]}{2\sqrt{R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \end{cases} \quad (18)$$

$$\begin{cases} N_x = \sigma \sqrt{\frac{X_0^2 [5Y_0^2 Z_0^2 + 8Z_0^4 - X_0^2 (27Y_0^2 + 40Z_0^2)]^2}{4R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \\ N_y = \sigma \zeta \frac{-Y_0 [-18X_0^4 + Z_0^2 (Y_0^2 - 2Z_0^2) + X_0^2 (9Y_0^2 + 28Z_0^2)]}{2\sqrt{R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \\ N_z = \sigma \zeta \frac{-3Z_0 [-8X_0^4 + Y_0^2 Z_0^2 + X_0^2 (Y_0^2 + 8Z_0^2)]}{2\sqrt{R_0 (Z_0^2 - 3X_0^2) [Y_0^2 Z_0^2 + X_0^2 (9Y_0^2 + 16Z_0^2)]}} \end{cases} \quad (18)$$

$$R_0 = \sqrt{X_0^2 + Y_0^2 + Z_0^2}$$

为带电从星相对于主星的无量纲距离。 σ 的取值可以为1或者-1, 因此, 对于任意给定的悬浮位置, 都存在两个互为反向的人工磁场方向解。需要注意的是, 为了保证 N_x, N_y 和 N_z 都为实数, 无量纲坐标的分量必须满足: 当 $X_0 \neq 0$ 时,

$$Z_0^2 - 3X_0^2 > 0,$$

也即

$$|Z_0| > \sqrt{3} |X_0|;$$

当 $X_0 = 0$ 时，则没有以上约束条件。另外， ζ 为式

$$X_0 [5Y_0^2 Z_0^2 + 8Z_0^4 - X_0^2 (27Y_0^2 + 40Z_0^2)]$$

的符号函数，定义为In the formula,

$$R_0 = \sqrt{X_0^2 + Y_0^2 + Z_0^2}$$

is the dimensionless distance of the charged secondary star relative to the host star. The value of σ can be 1 or -1, therefore, for any given floating position, there are two mutually opposite solutions of artificial magnetic field directions. It should be noted that in order to ensure that N_x , N_y and N_z are all real numbers, the components of dimensionless coordinates must satisfy: when $X_0 \neq 0$,

$$Z_0^2 - 3X_0^2 > 0,$$

that is

$$|Z_0| > \sqrt{3} |X_0|;$$

When $X_0 = 0$, the above constraints do not exist. In addition, ζ is the formula

$$X_0[5Y_0^2Z_0^2 + 8Z_0^4 - X_0^2(27Y_0^2 + 40Z_0^2)]$$

The symbolic function of ζ , defined as

$$\zeta = \begin{cases} 1, & \text{if } X_0[5Y_0^2Z_0^2 + 8Z_0^4 - X_0^2(27Y_0^2 + 40Z_0^2)] \geq 0 \\ -1, & \text{if } X_0[5Y_0^2Z_0^2 + 8Z_0^4 - X_0^2(27Y_0^2 + 40Z_0^2)] < 0 \end{cases} \quad (19)$$

$$\zeta = \begin{cases} 1, & \text{if } X_0[5Y_0^2Z_0^2 + 8Z_0^4 - X_0^2(27Y_0^2 + 40Z_0^2)] \geq 0 \\ -1, & \text{if } X_0[5Y_0^2Z_0^2 + 8Z_0^4 - X_0^2(27Y_0^2 + 40Z_0^2)] < 0 \end{cases} \quad (19)$$

$$[x_0, y_0, z_0]^T$$

的悬浮所需的电流大小。Step 5: Determine any actual relative position based on the directional component of the artificial magnetic field solved in Step 4

$$[x_0, y_0, z_0]^T$$

The amount of current required for the suspension.

The present invention uses three superconducting coils to construct an artificial magnetic field on the main star. Patent Citations (5)

As shown in Figure 2, the number of turns n_c and the radius r_c of the three coils are the same, and magnetic



fields in different directions are realized by adjusting the current in the coils. The relationship between the magnetic flux B_0 and the coil parameters is as follows

Publication number	Priority date	Publication date	Assignee	Title
CN103991559A *	2014-05-28	2014-08-20	中国人民解放军国防科学技术大学	Hovering control method for Lorentz spacecraft
US20160004250A1 *	2014-07-03	2016-01-07	James Pan	Ultra High Speed Navigation Magnetic Satellite and Unmanned Aircraft
CN108280262A *	2017-12-22	2018-07-13	西北工业大学	A kind of accompanying flying rail design method based on Lorentz force

Among them, $\mu_0 = 4\pi \times 10^{-7} \text{ N/A}^2$ is the vacuum permeability, and i_c is the current intensity in the coil. Denote i_c

* as the nominal current, then the current in the three coils can be expressed as follows	2018-12-11	2019-05-17	上海航天控制技术研究所	Relative pose couples isomorphism integrated dynamic modeling method between a kind of star
US20190168897A1 *	2019-01-09	2019-06-06	James Wayne Purvis	Segmented Current Magnetic Field Propulsion System

Family To Family Citations

* Cited by examiner, † Cited by third party

Non-Patent Citations (2)				
$\begin{cases} i_x = i_c^* N_x \\ i_y = i_c^* N_y \\ i_z = i_c^* N_z \end{cases} \quad (21)$				
SIYANG ZHANG ET AL.: "Two-Craft Lorentz Force Formation Dynamics and Control", 《2016 IEEE CHINESE GUIDANCE, NAVIGATION AND CONTROL CONFERENCE(CGNCC)》 *				
孙俊 等.: "地球轨道航天器编队飞行动力学与控制研究综述", 《力学与实践》 *				

In the formula, i_x , i_y and i_z correspond to the magnitude of the current in the superconducting coil along the x-axis, y-axis and z-axis, respectively.

Publication	Publication Date	Title
Beletskii et al.	1993	Dynamics of space tether systems
Ness	1965	The earth's magnetic tail
Shrivastava et al.	1983	Satellite attitude dynamics and control in the presence of environmental torques: A brief survey
CN107065565B	2019-03-07	A kind of Auto-disturbance-rejection Control pulled for cluster spacecraft electromagnetism
CN109240340B	2020-04-24	Lorentz force multi-satellite formation configuration method based on quasi-periodic orbit

Publication	Publication Date	Title
Huang et al.	2017	Fully actuated spacecraft attitude control via the hybrid magnetocoulombic and magnetic torques
CN108280258A	2018-07-13	A kind of accompanying flying rail design method based on Lorentz force
Kong	2002	Spacecraft formation flight exploiting potential fields
Gros	2017	Universal scaling relation for magnetic sails: momentum braking in the limit of dilute interstellar media
CN106200376B	2019-03-05	A kind of non-Kepler's suspension railway joining method of spacecraft day heart

计算出磁通量 $B_0=3.1416\times10^{-4}\text{T}\cdot\text{m}^2$ 。另外，取角速度比值 $\beta=1\times10^{-4}$ ，也即主星上人工磁场的自旋角速度为 $\omega_c=0.72922\text{rad/s}$ ，带电从星的荷质比

Dicke	1979	Do solar-type stars have magnetic cores-A question of stability
CN11446888B	2021-07-30	A Lorentz force levitation method based on artificial magnetic field
Peng et al.	2017	Formation-flying planar periodic orbits in the presence of intersatellite Lorentz force
Alpatov et al.	2010	Dynamics of Tethered Space Systems.
Djordjević	2018	Review of solar magnetic sailing configurations for space travel
CN108181925A	2018-06-19	A kind of more satellites formation configuration designing methods based on Lorentz force between star

从而得到单位长度

Ashida et al.	2014	Full kinetic simulations of plasma flow interactions with meso-and microscale magnetic dipoles
Lee et al.	2024	Sun-Earth harmonic orbit via Earth-Moon resonance orbit
Turner et al.	2024	Evidence of a thick heliopause boundary layer resulting from active magnetic reconnection with the interstellar medium
Shayak	2017	A mechanism for electromagnetic trapping of extended objects

的值。然后，将实际所需的悬浮位置坐标

Chen et al.	2022	Concept design and intelligent control of solar sail with numerous discrete elements
Bokelmann et al.	2015	Periodic orbits and equilibria near jovian moons using an electrodynamic tether

km转化成无量纲的位置坐标

Amaro et al.	2021	Formation flying control of the relative trajectory shape and size using lorenz forces
Götz et al.	2022	Solar wind interaction with a comet: evolution, variability, and implication
Polatov	2001	Magnetic propulsion systems

。最后，利用公式(18)可计算得到 $N_x=0.0118,N_y=-0.0012,N_z=-0.0288$ ，并带入公式(21)即可得到三个超导线圈中的电流大小分别为 $i_x=0.0118\text{A},i_y=-0.012\text{A},i_z=-0.0288\text{A}$ 。只考虑 $x_0\neq0$ (that is, $x_0\neq0$), and

randomly select the actual floating position as

Priority And Related Applications

Priority Applications (1)



